Soil Property Determination for a Seismic Study

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SYNOPSIS Static and dynamic soil property data were needed for input into the seismic retrofit design for the I-155 Mississippi River crossing located near the center of the New Madrid Seismic Zone. Soils consisted of recent river alluvium underlain by very dense soils of the Mississippi embayment. The field investigation consisted of conventional borings, downhole geophysical tests to measure shear wave velocity, and seismic piezo-cone soundings. SPT energy measurements were made at one boring to confirm hammer energy for liquefaction evaluation. This paper summarizes the data and provides site specific correlation of shear wave velocity vs. N-value from the seismic cone and downhole geophysical tests; measured SPT energy value; and estimates of static and dynamic soil properties.

INTRODUCTION

The bridge site lies near the center of the New Madrid Seismic Zone near Caruthersville, Missouri (Figure 1).

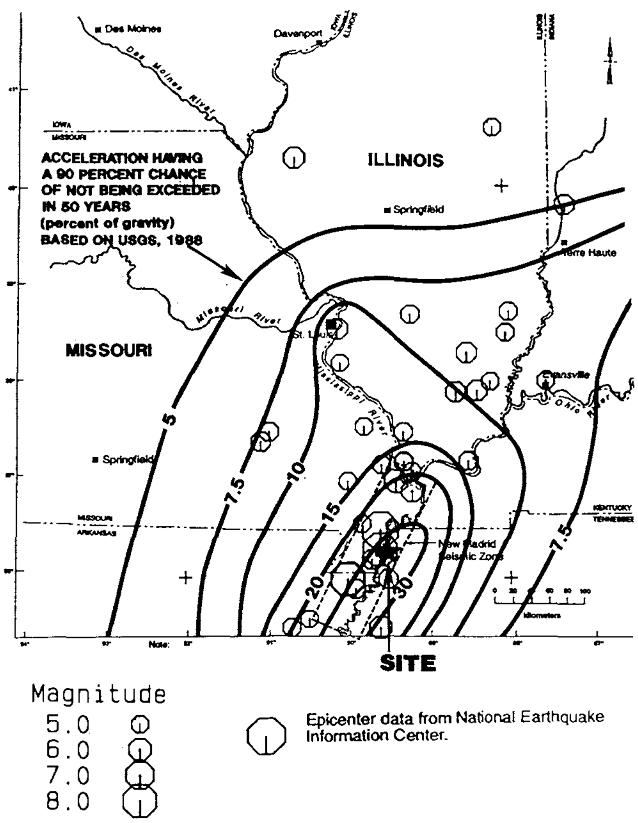

Fig. 1. Site Location and Regional Seismicity

Constructed in the early 1970's, the I-155 bridge consists of three segments: the 1,030 ft long Missouri approach, the 3,590 ft long main channel crossing and the 2,400 ft long Tennessee approach. The I-155 Bridge is the only bridge across the Mississippi River between Memphis, Tennessee and Cairo, Illinois. Design drawings indicate the approach spans are supported on driven piles; either H-pile, precast concrete, or cast-in-place concrete piles. Piles bear in very dense/hard Tertiary soils underlying shallow river alluvium. Pile lengths vary from approximately 40 to 85 ft at the Missouri approach and reach 75 ft at the Tennessee approach. The main truss channel crossings are supported on three caissons which bear on the Tertiary soils about 80 ft below the mudline. Soil properties were needed for seismic evaluation and preliminary retrofit design, however, the only data available were 26 borings completed for the original construction. This study was done to supplement the existing subsurface data.

FIELD INVESTIGATION

The investigation included; three test borings, six seismic cone; and four piezo-cone penetration test soundings along the Tennessee approach. The seismic cone was used to evaluate soil strength as well as shear wave velocity measurements. In addition, conventional downhole shear wave velocity measurements were made to a depth of approximately 140 ft near a approach span pier. Test borings included Standard Penetration Test (SPT) measurements as well as collection of undisturbed samples for triaxial testing. To estimate SPT energy for input to the liquefaction study, a subcontractor was retained to make hammer energy measurements.

SPT Energy Measurements

The energy delivered during the SPT tests was measured in one boring at seven depths ranging from 15 to 65 ft. The N-values determined for this study were made with a "Donut hammer" using a cathead and rope system, and AW-drill rods. Energy measurements were obtained by adding a 2 ft length of drill steel instrumented with accelerometers and strain transducers on the top of the AW rods and below the hammer. Test results indicated that the actual SPT energy in the system varied from between 51 and 63 percent and averaged 57 percent of the theoretical energy. This is greater than the typical value of 45 percent reported by Seed for Donut hammers (Seed, et al, 1985) as shown in Figure 2.

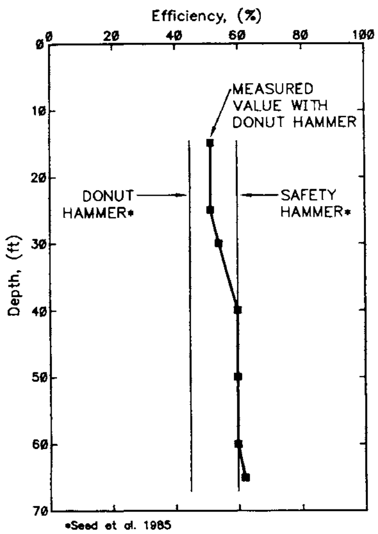

Fig. 2. System Efficiency vs. Depth

Downhole Geophysical Measurements

Downhole geophysical measurements were made to estimate shear wave velocity which was used to estimate the small strain shear modulus (G_{max}). This information assists in providing a better estimate of the dynamic properties of the soil. The measurements involved a vibration source located at the ground surface near the borehole and a receiver positioned in the borehole to detect pulses from the source. The travel times of the pulses at the known receiver depths were used to estimate the compression and shear wave velocities.

The vibration source consisted of a plank weighted down by a field vehicle. A sledge hammer was used to induce seismic signals by striking the end of the wooden plank. Both compression and shear-wave energy were generated and the corresponding vibrations were detected by the downhole sensors. The measurements were repeated on the opposite end of the plank, and the records were then compared for appropriate reversal of the shear-waves.

Cone Penetration Tests

Ten CPT soundings were made from grade to refusal which varied from 48.2 to 74.4 ft below grade. (CPT refusal meant that the maximum hydraulic pressure of a CME-750 drill rig had been achieved.) Seven soundings contained shear-wave velocity measurements at about 3 to 5 ft depth intervals using the seismic cone. The same general procedure of using a plank and sledge hammer used for downhole geophysical measurements was also used to obtain the shear-wave measurements for the CPT tests. Results of the shear-wave velocities versus depth for the downhole geophysical measurements and the seismic cone sounding (made within 10 ft of the downhole measurements) are almost identical as shown in Figure 3. Note, however, that due to limitation of the drilling equipment, seismic cone data were only measured until refusal (N < 60).

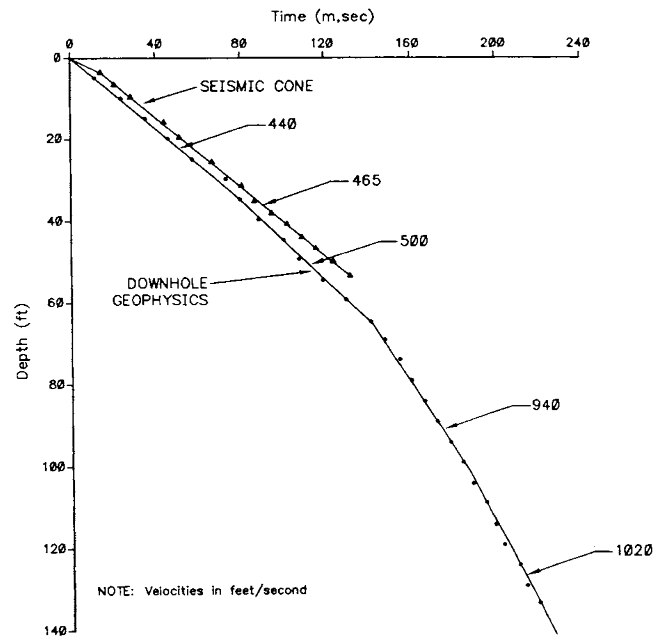

Fig. 3. Downhole Travel Times and Average Shear Wave Data

SPT blow counts were empirically obtained for the CPT tests by using Robertson, et al, 1986. Shear wave velocities were plotted against SPT N-values in Figure 4. Except for one data point, both methods generally plot in the same range. The reason for the one outstanding point is not clear but may be due to the general scatter in correlation between shear-wave velocity and N-value. Recommended average correlations by others is also shown in Figure 4. The correlation at this site is below recommended correlations, but is within the scatter band of data on which the correlation was based.

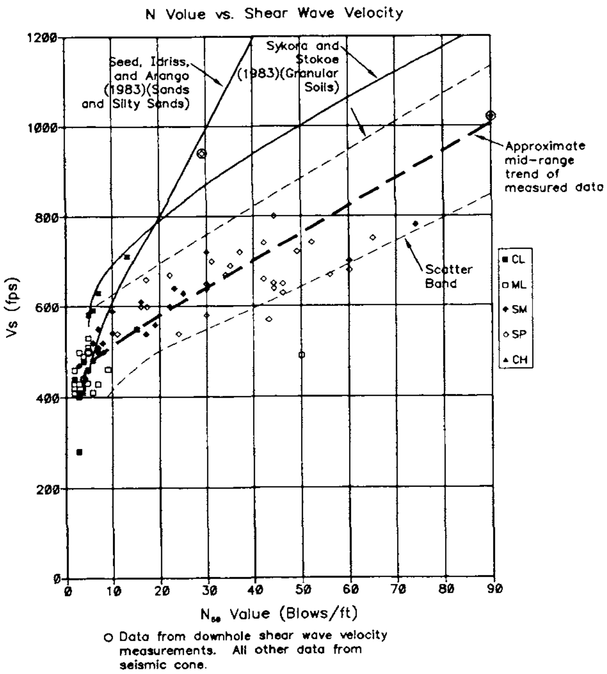

Fig. 4. Shear Wave Velocity vs. N-value

SUBSURFACE CONDITIONS

The site is located within the flood plain of the Mississippi River and the shallow soils consist of varying types of river alluvium. The alluvium is underlain by very dense soils of the Mississippi Embayment consisting of sand, gravel, and very hard clay estimated to extend about 2700 ft to bedrock, (Grohskopf, 1955).

Soil Properties were correlated between the borings drilled for this investigation and the original investigation borings of the 1960's using Standard Penetration Test N-values, soil descriptions, and laboratory index tests. Although these correlations are approximate, it was the only geotechnical data available. Based on these correlations, eight key soil strata were identified. Dynamic soil properties were assigned to these eight strata. The generalized subsurface profile of the site is shown in Figure 5.

Soil strata and properties shown in Figure 5 are average values. Soil type and equivalent N-values were determined in CPT soundings were based upon correlations to adjacent borings with guidance from published correlations (Seed and De Alba, 1986). Soils were grouped into two primary soil types: clays and sands. Silts were included within either category depending on whether they were generally clayey (plastic) or non-plastic. The two soil types were the subdivided based upon SPT and correlated CPT N-values.

Small strain shear modulus (G_{max}) was estimated from the shear-wave velocity. Where shear-wave velocity data were not available, the shear-wave velocity was estimated based on the correlation shown in Figure 4. This correlation shows significant scatter; however, it is generally within the scatter band reported by others (Sykora, 1978).

Undrained shear strength of the clay was measured using laboratory tests. The laboratory testing included unconfined compression tests and consolidated undrained triaxial tests. The CPT undrained shear strength data was based upon a cone factor N_k of 15.

Friction angle of the granular materials was estimated from soil type and relative density based on N-value correlations by the U.S. Navy (1986).

Relative density was based on N-value correlations reported by Tokimatsu and Seed (1987) and also from the cone penetration resistance correlations by Robertson (1989).

CONCLUSIONS

Conclusions of this case history can best be summarized as follows:

- Downhole geophysical testing and Seismic cone data provided nearly identical shear-wave velocities
- Poor correlation was found between N-values and shear-wave velocities
- Shear-wave velocities measured were less than published correlations to N-values
- The measured average donut hammer energy of 57 percent of the theoretical energy was higher than the published value of 45 percent.

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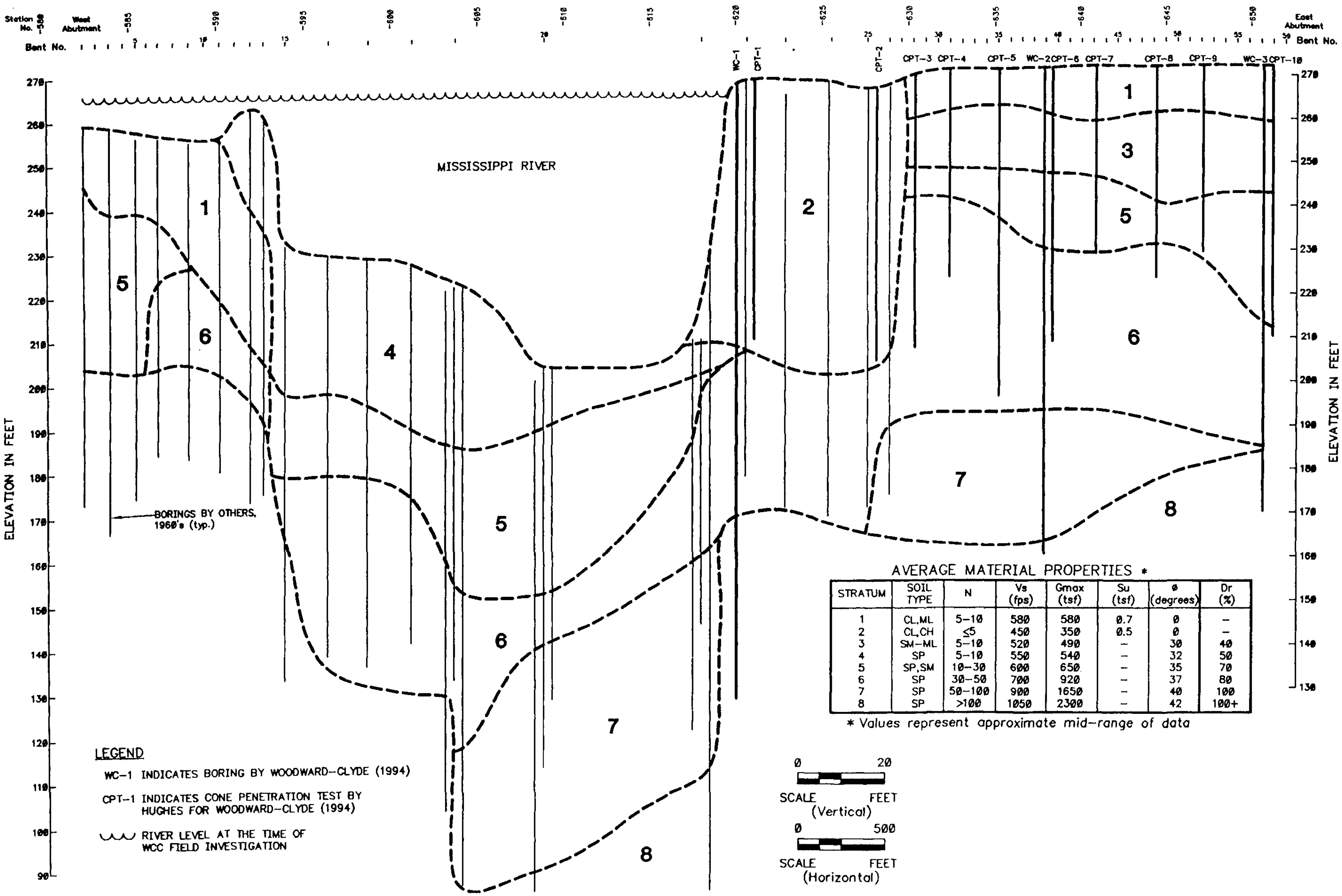

STRATUM	SOIL TYPE	N	Vs (fps)	Gmax (tsf)	Su (tsf)	ø (degrees)	Dr (%)
1	CL,ML	5–10	580	580	0.7	0	–
2	CL,CH	≤5	450	350	0.5	0	–
3	SM–ML	5–10	520	490	–	30	40
4	SP	5–10	550	540	–	32	50
5	SP,SM	10–30	600	650	–	35	70
6	SP	30–50	700	920	–	37	80
7	SP	50–100	900	1650	–	40	100
8	SP	>100	1050	2300	–	42	100+

* Values represent approximate mid-range of data

Fig. 5. Interpreted Subsurface Profile

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